

Harmonic quarks: properties and some applications

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Abstract

In this work the investigation of hadronic structures with the help of the harmonic quarks is prolonged. The harmonic quark model is good at describing the meson structures and the baryon excitations to resonances, in particular delta(1232). Harmonic quark reactions form the structure of the baryon resonances. Presumed quark structures of the mesons eta(548), omega(772), a(980) and f(980) are given. It became clear that the some hadronic structures contain the filled quark shells. The kinetic quark energy in the basic charged mesons are enough small for a using of perturbative methods. The following topics are briefly considered and discussed: harmonic quark series and its boundaries, the d-quark peculiarity, parallel quark series and quark mixing. The boundaries of quark chain can be closely related to a weak interaction. The cause of the quark mixing is probably an existence of the parallel quark chain and the special properties of the *d*-quark in the main quark chain. The new mass equation is found. It is probably a manifestation of Higgs mechanism. Using this equality enables to improve the accuracy of the harmonic quark masses calculation to 0.005%. The strong interaction should take into account the harmonic quark annihilation.

1 Introduction

In article [1] on the basis of the harmonic quark oscillator we built a simple quark model, in which the quark masses are connected by the recurrent equations:

$$\frac{m_n}{m_{n-1}} = \frac{\pi}{(4 - \pi)} = 3.6597924 \stackrel{\text{def}}{=} MQ \quad (1)$$

or so

$$m_n = m_0 \left[\frac{\pi}{4 - \pi} \right]^n \quad (2)$$

where m_0 is a hypothetical initial quark mass; m_n is the quark mass of quark flavor number n .

Further we calculated the harmonic quark masses with the $\approx 0.03\%$ inaccuracy (table 1).

Table 1. The masses of harmonic quarks.

n (flavor)	1	2	3	4	5	6	7
quark	<i>d</i>	<i>u</i>	<i>s</i>	<i>c</i>	<i>b</i>	<i>t</i>	<i>b'</i>
mass (MeV)	28.815	105.456	385.95	1412.5	5169.4	18919	69239

Then we started to show actual serviceability of the harmonic quarks. So, to apparent results concern a solution of secret of an origin of mass of a muon and interpretation quark structure of a neutral pion. It seems that **neutral pion with great share of probability is a stationary harmonic oscillator based on quark-antiquark u -pair**. The pion mass is more the oscillator mass on 0.7 MeV, that together with Coulomb energy of pair provide a kinetic energy of u -quarks up to some MeVs. The next obvious conclusion is that **muon is a successful attempt of Nature to explicitly fix the single u -quark mass state as a lepton suppressing color and fractional charge**. So, main decay canals of π^\pm and K^\pm is μ and ν , then hence d -quark and s -quark disintegrate in these mesons much more often than u -quark. Probably electric and colour charges of d -quark and s -quark transfer to u -quark and then μ shall born. We do not know, as a color charge is suppressed and as the lepton numbers are formed. Important only that such process can occur but it is beyond the framework of the present article.

In this work we shall prolong an examination of hadronic structure with help of the harmonic quarks and quark oscillators. Besides we shall prolong to study the properties of our harmonic model and we shall discuss a controversy on problems and corollaries generated by this model.

2 Harmonic quarks in hadrons

The harmonic quark applications to hadronic structures are below started.

2.1 Quark reactions

Harmonic quarks demonstrate a very good serviceability at the description of baryons and their resonances. We shall consider a simple quark reactions only for the following pairs of particles: $\Lambda(1115)$ and $\Sigma^0(1192)$, $\Lambda(1115)$ and $\Sigma^0(1385)$, nucleon and $\Delta(1232)$.

1. After the electromagnetic transition of $\Sigma^0(1192)$ to $\Lambda(1115)$ the baryon mass decreases by 76.96 MeV. The transition of $u\bar{u}$ quark pair to the harmonic oscillator

$$u + \bar{u} = (u\bar{u})_{ho}$$

is accompanied by the mass decrease of 76.63 MeV.

2. Now we shall write a simple quark reaction of $\Lambda(1115)$ excitation up to $\Sigma^0(1385)$ with the mass of 1383.7 ± 1.0 MeV [2]:

$$\Sigma^0(1385) = \Lambda(1115) + u\bar{u} + d\bar{d}$$

From here the mass of $\Sigma^0(1385)$ is $1115.7 + 2(105.4 + 28.8) = 1384.1$ MeV, which is in complete accord with the experimental measurements. The main channel of the $\Sigma^0(1385)$ triplet decay (88%) is $\Lambda(1115)\pi$.

3. The pion-nucleon scattering has the first peak at the aggregate energy of 1232 MeV, which is known as the first delta baryon. Note how simply and gracefully this resonance can be obtained from the transformation reaction of a d -quark pair into a u -quark pair

$$d_{\text{nucleon}} + \bar{d}_{\text{pion}} = u_{\text{delta}} + \bar{u}_{\text{delta}}$$

with the mass of $\Delta(1232)$ equal to $939.6 + 139.6 + 2(105.4 - 28.8) = 1232.4$ MeV, this is also in a complete accord with experimental data.

2.2 Quark structure of some light mesons

We shall now determine the plausible structure of light mesons by “sequentially filling” them using quark masses obtained. That is, we would first “fill” the meson mass with the heaviest possible quark, then again “fill” the rest of its mass with the heaviest possible quark, etc. As pion and kaon were already discussed, let’s take the next particle: $\eta(548)$. The sequential filling of its mass immediately produces the harmonic quark structure $s + u + d + d$ with the desired mass of 549 MeV. Quite acceptable. It’s rather easy to interpret this result with the help of a harmonic oscillator concept. The total mass of the su pair is equal to the mass of stationary harmonic oscillator based on a strange quark-antiquark pair. The remaining light quark pair forms a filled outer neutral shell of $1s^2$ kind. On the whole the $\eta(548)$ structure is similar to helium atom—a heavy nucleus formed by a stationary harmonic oscillator and a relatively light filled outer shell. The analogy can also be drawn to helium nuclei, which has two filled $1s^2$ shells of two protons and two neutrons. Beside that, note the similarity between $\eta(548)$ and π^0 . Both particles supposedly contain a harmonic oscillator.

Now let’s consider the structure of $\omega(782)$ vector meson, which is generally agreed to contain hidden strangeness. The strange $s\bar{s}$ pair has total mass of 772 MeV which is only 10 MeV less than the meson mass. The $\omega(782)$ differs from all particles formerly discussed, as it contains the separated quark-antiquark pair of the same flavor. This pair is completely separated to distinct entities with certain quark-related restrictions. As in π^\pm and K^\pm mesons case the s -quarks of $\omega(782)$ demand an additional energy: a kinetic energy and probably the energy to hold the quark spins in the same direction.

We will not discuss the $\rho(770)$, K^* and $\eta(958)$ mesons, for their structure is somewhat more complicated, but will say a few words about $a(980)$ with mass value of 984.8 ± 1.4 MeV and $f(980)$: 980 ± 10 MeV. The sequential filling provides the $s + s + u + u$ quark structure with total mass value of 982.9 MeV. Another reasonable result. Though this case is more intricate as the $a(980)$ is a triplet. Therefore this structure supposedly describes the $f(980)$ meson only. There’s two filled neutral shells of a $1s^2$ kind here based on $s\bar{s}$ and $u\bar{u}$. The $a(980)$ triplet structure resembles the structure of $\rho(770)$ triplet, as they probably differ by one quark-antiquark $u\bar{u}$ -pair only (211 MeV) with the extra kinetic energy of several MeVs.

Thus we can see that harmonic quarks provide us with a completely new insight of meson structures. These examples of the harmonic quark model usefulness could be easily prolonged. Though the ones presented here should suffice to realize the model potential. It seems we had actually found a new powerful tool of hadronic (and other particles) structure determination.

2.3 Quark state in π^\pm , K^\pm and b^\pm mesons

Using precise values of quark masses one can easily obtain quark velocity limits and minimal inter-quark distances in charged pseudo-scalar mesons of π^\pm kind. Estimating minimal inter-quark distances we would assume that a colour interaction on these distances is small, hence the quark kinetic energy would transform to Coulomb energy as the quarks draw near each other. The maximum velocities presented in table 2 are given in light unit and calculated at the force balance moment between Coulomb and color fields.

Table 2. Maximum quark speeds and minimal inter-quark distances in π^\pm , K^\pm and b^\pm mesons

Meson	Additional quark energy MeV	maximum u -quark velocity	maximum 2nd quark velocity	minimal inter-quark distance, fm
π^\pm (ud)	5.32	0.146	0.487	0.052
K^\pm (us)	2.32	0.183	0.051	0.12
b^\pm (ub)	4.9 ± 0.5	0.29	0.006	0.057

It can be concluded that quarks in charged mesons are not very relativistic. It's the only lightest d -quark that reaches half light speed in a pion. The data in table 2 convince us that a perturbative methods would be used for investigation of these mesons on the based of the harmonic quarks.

3 Harmonic quark properties and discussion

We shall now investigate the consequences of the presented harmonic quark family and other matters ensuing from the model and the quark masses. It's a well-known fact that harmonic oscillators play a significant part in classic field theory [3, 4], are a "perfect model" and "everywhere" [4]. The model quark spectrum bears a resemblance to the simple harmonic oscillator (with $(n + \frac{1}{2})\omega$ energy spectrum). Both of them are equidistant with the only difference being that the first on a normal and the second on a logarithmic scale (1). Just as a simple harmonic oscillator has the zero state, we can single out the zero state namely the zero quark (eq. (2) at $n = 0$), that is the hypothetical initial mass (energy) $m_0 \cong 7.87$ MeV. The author believes that harmonic quark masses are actually their physical masses. Anyway, there are reasons to believe that this harmonic quark energy spectrum is the spectrum of the eigenstates of a certain interacting field. If that is the case, we are up to solving the inverse

problem: to find the field using its eigenstates. The ground state of the quark-antiquark pair is a harmonic oscillator based on it. It is probably the most coupled state, for all two-quark meson masses are greater than the masses of corresponding harmonic oscillators: pions masses are greater than u -oscillator energy, the same with kaons and s -oscillator, etc. If the coupled energy were any greater, the quarks should probably lose their individuality.

3.1 Quark family boundaries

As the quark model presented forms a rigid series from the quark family, it's inevitable to wonder about the lower and upper boundaries of it. There is not much doubt about the lightest quark of the series—it's the d -quark (28.8 MeV). The particle physics doesn't currently know the charged meson lighter than π^\pm , which contains d -quark and u . Quark lighter than d -quark would have 7.87 MeV mass value, and corresponding meson 40-50 MeV. The termination of the series from below may be occurs because of the electron-positron field. The upper boundary of the quark series, i.e. the heaviest existing quark is still a mystery. For heavy quarks t , b' and t' the model mass values are 19 GeV, 69 GeV and 253 GeV respectively.

The t' -quark mass would be three times more that of W -boson. Therefore it is only logical to assume that the termination reason from above could be weak interaction with its characteristic distance and energy scales.

Unifying the reasons one can say that the quark series may be limited from both sides by electroweak interaction. Thus in the energy range from zero to W and Z bosons there are seven harmonic quark flavors.

It's interesting to mention that a hypothetical initial quark mass $m_0 = 7.9$ MeV in (1) lies very close to the d -quark bare mass and the mass value of $\frac{1}{2}(u + d)$ combination, computed with the help of \overline{MS} -schemes and lattice simulations [2].

3.2 Parallel quark series

Alongside with the quark series already discussed, which we shall name “basic series”, one can easily imagine another “unrealized” parallel quark series with the same harmonic relations (2) and the same mass values. The only difference between the series is the “charge shift” by one position. Thus, parallel quarks with mass values of 28.8 MeV and 105.4 MeV would have the charges of $\pm\frac{2}{3}$ and $\pm\frac{1}{3}$ respectively, etc. The reasons for Nature preference of the basic series to the parallel series are unknown at present. It may be somehow connected with the special features of the d -quark. For example, there could be some reasons for the lightest quark to necessarily have the charge of $\pm\frac{1}{3}$. The d -quark position in the quark chain is distinguished already. Any other quark has two neighbors, which can be thought of as an upward and downward excitation, but the d -quark has only an upward excitation. In a sense it is an “inferior” quark. It can be to some extent considered as an appendix to the u -quark. The isotopic properties of the d - and u -quarks is likely to lie there. Furthermore this

could be an approach to solving the quark mixing problem, as the mixing can be a partial manifestation of the parallel series.

3.3 Leptons

The successful decision of a muon mass problem on the basis of u -quark stimulate us to review the process of the τ -lepton mass formation too. The c -quark mass is apparently close to the τ -lepton mass and the author believes that the τ -lepton may be formed on the mass basis of c -quark. The existing mass difference between them of 364 MeV should have a good reason and needs to be explained. This is less than the neighboring s -quark mass and moreover it can't be the s -quark. Otherwise we shall receive a meson. At the same time τ -lepton mass is less than the mass of the harmonic c -oscillator and also than the lightest D -meson mass, which contains explicit charm. One can suppose that this additional energy is required for suppression both color and fractional electrical charges on the c -quark, but it is not enough for D -meson formation. Both the τ -lepton and the muon in it are similar. Their masses are located below masses of the first mesons of the appropriate quarks. One could also suppose that the massive leptons could only be based on harmonic quarks with the $\pm\frac{2}{3}$ charge, ignoring the quarks with charge of $\pm\frac{1}{3}$. The existence of the super-heavy charged lepton based on the harmonic t -quark is not likely due the following: there are no known hadrons with the explicit t -flavor, which means that solitary t -quark existence without t -antiquark is suppressed for some reason, therefore the individual mass basis to form the super-heavy lepton on does not exist. Furthermore, the experimental and theoretical works testify to that there are only three light neutrinos [2], which is also a good argument against the existence of the fourth pair of leptons.

From the supposed point of view there is necessary the some updating the symmetry with lepton-quark generations.

- The harmonic quarks are bound in one chain, instead of broken-down on three generations.
- The muon and the τ -lepton are formed on the mass basis of quarks with a charge $2/3$, that does the quarks as though by more fundamental fermions.
- An electron is not bound in any way with quark set and it, probably, really formed on the basis of QED vacuum.

3.4 Is it the Higgs mechanism manifestation?

The muon formation of u -quark mass state singles out this quark from the quark series too. The u -quark is a lightest quark with the charge of $\frac{2}{3}e$ which has both two neighbors. It is as though it was a first full-fledged quark with a full-fledged properties and should be considered in details as such. The fully color neutral group based on this quark, i.e. three colors and three anti-colors (let's name it $6u$ -boson) turns out to have the mass value of 632.736 ± 0.18 MeV. And the

total mass of the first two neutral particles π^0 and K^0 also have the same value: 632.649 ± 0.03 MeV. Pion is a truly neutral particle, and kaon in the long-term sense (mean integral) is also truly neutral, as it is able to pass between “particle” and “antiparticle” states. Thus we have a mass equality of two truly neutral groups. The author believes this not to be a coincidence, but the component of Higgs mechanism, the true meaning of which is still unknown. Nonetheless we can use this equality. The inaccuracy of u -quark mass determination can be improved six fold with its help, and harmonic quark masses can be obtained with 0.005% inaccuracy.

Table 3. Precise mass values of the harmonic quarks, MeV

meson	d	u	s	c	b	t	error, %
b^\pm [1]	28.815	105.456	385.95	1412.49	5169.4	18919.0	± 0.030
$\pi^0 + K^0$	28.8108	105.441	385.894	1412.29	5168.7	18916.3	± 0.005

4 Conclusion

The author believes that harmonic quark masses are actually their physical masses. We can see that the harmonic quark annihilation plays a significant role in strong interaction. The harmonic quark annihilators can be directly bound with a bundle of space and can appear the elementary boson excitations of a vacuum. The harmonic bound states of quarks should find the place in the QCD Lagrangian. The simple recurrent equation for quark masses and their precise binding to energy scale will considerably reduce the number of the free parameters of the Standard Model.

References

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